The Power-Aware Cord: Energy Awareness through Ambient Information Display

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ABSTRACT
In order to support increased consumer awareness regarding energy consumption, we have been developing new ways of representing and interacting with energy in electric products intended for domestic environments. The 'Power-Aware Cord' is a re-design of a common electrical power strip that displays the amount of energy passing through it at any given moment. This is done by dynamic glowing patterns produced by electroluminescent wires molded into the transparent electrical cord. Using this fully functional prototype, we have been investigating how such ambient displays can be used to increase energy awareness. An initial user study indicates that the Power-Aware Cord is a very accessible and intuitive mean for better understanding energy consumption. Future work includes further development of the mapping between load and visual pattern and in-depth studies of user perception and learning over time.

Keywords
Ambient displays; Interaction design; Conceptual design; Energy efficiency; Ubiquitous computing; Augmented reality; Physical device UI.

ACM Classification Keywords
H.5.1 [Information Interfaces and Presentation (e.g., HCI)]: Multimedia Information Systems – *augmented realities*.

INTRODUCTION
Electricity is both invisible and intangible. We can see, feel, hear and even smell its effects, but we can not really perceive it. As the effects of electricity (light, heat and so on) often are taken for granted in our domestic homes today, electricity becomes even more invisible.

In order to support increased awareness in the area of consumer energy consumption, on a large scale in society as well as on the mundane level of the home, it is crucial that people learn about different amounts of energy used by the electric products in their everyday life. If this awareness is increased, people might gain control over their own local relationship to this invisible global resource. Ultimately this will lead them to question their energy behaviours.

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In order to support increased energy awareness we have designed the 'Power-Aware Cord', an augmented, re-designed electrical power strip, in which the cord visualizes the invisible electricity used. Thus, the user interface of the Power-Aware Cord is the same as for any ordinary electrical power strip, with the addition of a dynamic visualization along the cord where the current use of electricity is represented through glowing pulses, flow, and intensity of light. In this way the entire cord acts as an ambient display to inform users of electrical current passing through en route to electrical appliances plugged into the extension sockets.

We argue that using light is a more natural and intuitive way of symbolizing energy than Watts on a numerical display (user observations indicate this to be a fact amongst the majority). Watts are a symbolic construction that can be hard for users to relate to. Light, however bears some resemblance to the real world since perceiving it is actually to register a form of energy.

In this paper, we present the use of information technology and design in an electric product with an ambient interface that is both simple and intuitive, for everyday use and learning, in a domestic context.

We present arguments for the advantages with this concept compared to traditional display approaches in informing users of their actions and choices. We also address the problems that surfaced once the idea was converted into prototype. Additionally, we will summarize user feedback gained from an initial test of the Power-Aware Cord.

CREATING ENERGY-CONSUMPTION AWARENESS
In terms of human computer interaction, the Power-Aware Cord can be described as a visual overlay of digital information on a real world object. It can therefore be seen as an example of augmented reality. Wendy Mackay [4] describes three types of augmented reality, in which the user, the environment, or (as in this case) the object might be augmented. In embedding the underlying technology in in the real world and augmenting everyday objects, our work also relates to the areas of ubiquitous computing and ambient displays [1].

The interface of the Power-Aware Cord invites users to plug in different appliances and experiment with how these relate to each other in terms of energy. Our idea is that, by integrating the information about electric flows where they actually are, will result in a more intuitive, playful and metaphorical display than what would normally be produced. Such an approach might inspire users of the Power-Aware Cord to explore and reflect upon the energy consumption of other electrical devices in their home, using the cord.

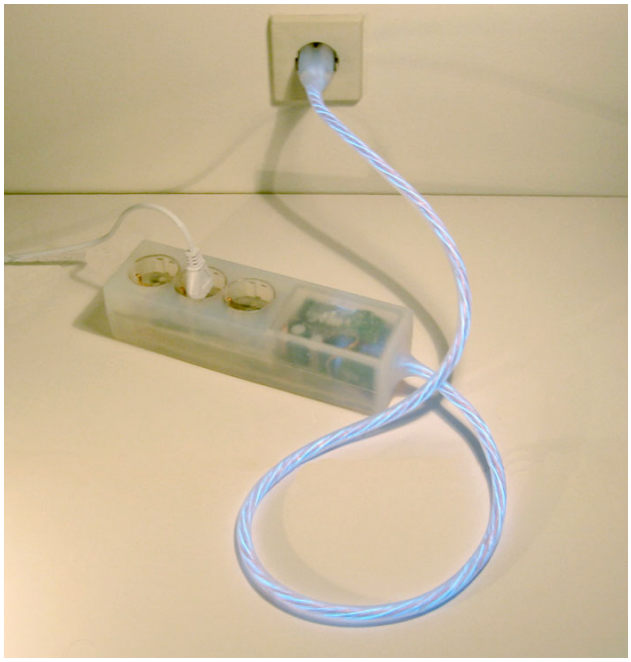

Figure 1. The Power-Aware Cord prototype.

Our aim is also that users might perceive the light patterns as the actual electricity in the cord, if not on a direct level then at least on an intuitive and metaphoric level. By this, we mean that people might talk about and refer to the light just as if it would be the electricity itself, even if they on a logical level would realize that it is just a representation.

With the Power-Aware Cord, users' actions, such as plugging or unplugging electrical devices into sockets, immediately result in a response from the cord, giving the user direct feedback and the feeling of both seeing and interacting with electricity. The rich affordances stemming from the Power-Aware Cord, as a tangible, real-world object adds to its intuitiveness [3].

Representing the amout of electricity with light, and not a numerical display, supports the notion of ambient information displays that does not force the user to walk up to the device but rather to receive the information at a glance from a distance. This enables the interface to be accessed from any place in the room in which it is situated, and thus constantly providing subtle information on energy usage. This could be useful in order to change behaviours and awareness over time or to detect unnecessary stand-by consumption.

Related Work

Studies of energy information displays in homes have been made in "The Effects of Information on Residential Demand for Electricity" by Isamu Matsukawa [2]. In this paper, he argues that consumers need information in order to act rationally. He establishes that the display used in this example does affect the energy consumption with its graphs and numerical information, even if the effect is small.

There are several attempts to visualize abstract information. Similarities to our concept can be found in Chatzitsakyris et al. proposed Ambient Media-implementations [1]. Here the geographical location of subway-lines was visualized by light in the side-walks of a city. In this ambient-media example, invisible occurrences in time and space are made visible, in reference to the time and space in which they occur.

"The videocard game" by Buur and Soendergaard, is an example of augmented reality, augmenting the object [5]. By embedding computer monitors into a table and providing physical playing cards with electronic ID tags, a tool for video analysis was created. The artifacts augmented in this example will very clearly appear augmented to the user.

The work by Raby & Dunne in their *Design Noir* [6] can be mentioned both as inspiration and related work in the way they design everyday objects that visualize hidden properties such as electromagnetic fields stemming from devices in the surroundings.

THE PROTOTYPE

The light in the Power-Aware Cord is obtained by the use of electroluminescent wire. This wire contains a phosphor layer that glows with an intensive blue-green light when an alternating current is introduced. Due to the color of the phosphor, the wire appears to be white when unpowered, a feature that greatly reduces its appearance in the device when unpowered. This hides the underlying construction from the user and adds to the unexpected experience when the device is powered and starts to glow. Since the cable will shift in colour when going from unlit to lit mode the user can easy detect low intensity levels.

Three luminescent wires are bound together with ordinary copper wires for electric conduction. The wires are twisted together to improve the flexibility of the resulting cable. Twisting the wires also gives the possibility to create an effect of motion through the cable by powering each of the three luminescent wires in turn. The whole structure is coated with a layer of transparent silicone.

The resulting functionality in the Power-Aware Cord is an extension cable capable of delivering up to 10 amperes load. The resulting power range that can be measured is 0 – 2200 W. The three microprocessor controlled light

segments in the cable can be set to any intensity independent of each other.

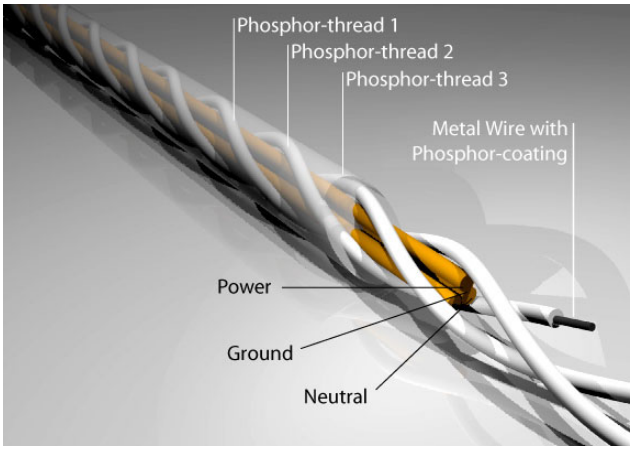

Figure 2. To make the light inside the cord simulate a flowing motion, the three threads are lit one at a time. Silicone protects all the wires.

Visual Interface

In the Power-Aware Cord, we want to display a wide range of information values (preferable the whole range from 0 to 2200 W). Ideally the user should still be able to recognize small differences like the one between a 40 W and a 60 W light bulb (20 W) and also be able to distinguish among effects observed on one day compared to those observed another day. Using intensity alone this is just not feasible.

Other examples of visualizing the effects in addition to using static intensity levels would be using frequencies in the form of pulsating light or, as mentioned earlier, movement induced by lighting the different light segments in turn. Pulsing the light could be done in numerous variations by changing variables such as attack and decay of the pulse or ratio between time lit versus time unlit could be used. A concern with using pulsating or moving light has been that these visualizations will become too intrusive on users perception.

User feedback

In an initial user test, three basic visualisations were examined: static intensity, pulsating intensity and flowing intensity. The initial test consisted of two parts: one for testing the intuitiveness and perception of the prototype and one for gaining feedback on the different mappings.

At the time of the initial test, the cable was not fully functional. We therefore decided on a Wizard-of-Oz approach during part one. Since the Power-Aware Cord at this stage had some loose contacts as well, we decided to not let the users operate the cord themselves. There was, in other words, no direct interaction possible for the users at this point. They were instead asked to observe one of the test leaders while a scenario was performed. Afterwards they were asked to describe what they had seen.

Fifteen people (4 women, 11 men) between the ages of 15 to 55 took part in the test. Static intensity, pulsating intensity and flowing intensity were tested on groups of 5 people each. The following results were obtained. All 15 people reported seeing the blue light in the cord. Thirteen of these perceived the blue light as a representation of the electrical current. The two persons that did not connect the light to the electrical current were both shown the static intensity program.

The second part focussed on finding out which of the three programs the test persons thought was the most pleasing and the most informative. The programs were demonstrated and the test people asked to rate them. The results showed that a constant glow, in varying intensities, was generally seen as calm and pleasing while the flow and the pulse were seen as the most informative programs. The pulsing light and the flow, at high levels were often seen as irritating. The median-values, from part two of the test, shows that the static intensity was considered less informative.

The flow or moving intensity was, as expected, easier to interpret than the static intensity. Something that was not predicted however was that pulsing intensity was also easier to interpret than the static intensity. One person remarked that he felt something being transported when the cord was pulsating compared to when it was shining in a constant level of intensity.

Another expected result was that the moving or pulsing programs would be rated more intrusive than the static intensity. To our surprise, some people found bright levels of the static intensity uncomfortable and consequently rated flowing intensity higher than static intensity in regard to comfort.

DISCUSSION

The overall response to the Power-Aware Cord was very positive. Most test persons seemed to easily grasp its functionality and immediately came up with examples of how they would use it. One woman explained how she would use it to teach her children about electricity. Others reflected on how it could be used to test stand-by products. Our test persons clearly saw the need for a device like the Power-Aware Cord. They also seemed to appreciate its pedagogical properties. A few persons expressed concerns such as: “It would be irritating when you sleep”.

Whether the users could perceive the light as actual electricity is more difficult to tell. One woman clearly did: she said, “I think this is what power cords look like on the inside. You have just made it transparent!” Most people, however, thought there was something more to it. This notion often seemed to derive from the socket box being bigger than usual. One person thought the light looked too harmless in order for it to be electricity. At another point, the Power-Aware Cord was compared to a bicycle dynamo “the faster it goes, the more it glows”, while someone else

compared it to a heart "it pumps the electricity at different speeds".

All except one of the fifteen test people were positive about having a Power-Aware Cord at home. Some saw themselves having several Power-Aware Cords in their homes while other expressed they might not use it as an everyday product but rather as a reference from time to time.

When compared to the related work presented, the Power-Aware Cord differs in several aspects. In Matsukawa´s paper [2], awareness is increased by monitoring energy consumption in the entire home. Our approach focuses on monitoring on a local scale of individual products. We go beyond the traditional display approach in contrast to, for example the display used in Matsukawa's paper, which uses numbers and graphs.

While most ambient display examples lie within the context of an architectural space, where an occurrence outside the room is visualized, our display is connected to a local occurrence. The display itself is physically connected to this local phenomena being visualized.

A critique of the Power-Aware Cord could be that the prototype in itself consumes electricity. We argue that if the user increases his or her awareness of energy consumption and understanding of relations between electrical devices, it is worth the small amounts of extra electricity used by the cord. In the long run, our hope is that the information given by the cord, and the increased awareness, will result in a more optimized consumption of domestic energy. If so, the cord's own consumption can be justified.

CONCLUSION

The Power-Aware Cord is clearly an experimental prototype. In our research, it is a tool for learning about people's perceptions about electricity. As a commercial product, the device could make people investigate and question their energy consumption as well as gain a stronger awareness in this area.

Initial user testing has proven the Power-Aware Cord to be a very intuitive and intriguing tool with an overall positive response from the test subjects. The actual usage of the cord remains to be seen. Which devices will the user choose to power with the cord and during which occations? In depth user studies in domestic environments are therefor the next natural step.

But prior to that, we intend to improve the visual mapping based on our initial test. Mapping between effect and visual pattern has become a question of how to combine different visual forms such as intensity, period and movement as well as of achieving a balance between visual comfort and the ability to convey enough information. So far, we have experimented with several different mappings. The final version will most likely be a combination of those. An example might be a flow representing the consumption with temporary intensity variations to indicate small changes. In cases of high consumption, the flow could start pulsating.

At this stage, the Power-Aware Cord is meant to be a conceptual design statement, mostly used to test people's reactions and provoke thoughts around the area of energy consumption. Through its form, its message will resonate in the form of ordinary power strips. At a more developed stage, our hope is that the prototype can be adopted as a home application.

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